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13. ABSTRACT (Maximum 200 words)

Laboratory studies and theory for three problems in Geophysical Fluid Dynamics were developed. In the first, buoyant flows driven by both differential heating and by imposing an inflow of salty water into water of lower salinity exhibit a number of features predicted by multiple equilibrium theory such as hysteresis and sensitivity to initial conditions. Present experiments also had an internal mixing coefficient which varied, and in some cases with small mixing time-dependent and internal oscillation were found. No explanation for the oscillation mechanism exists. In the second problem, the boundary layers for rotating stratified fluids were observed and compared with linearized theory. In the third, localized currents upstream of a control section for rotating fluid revealed new and unexpected features which are best explained by westward intensification concepts.

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Convection Processes in the Ocean-Laboratory and Theoretical Studies
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LONG TERM GOAL

My long-term goal has been to make observations in the laboratory and conduct associated theory of processes important in the ocean. Two projects were studied during the most recent two-year span of this grant and a third theory and experiment was developed more gradually, although recent experiments produced important and unexpected flows which are already submitted for publication. The first project is the behavior of convective flow driven by two distinct buoyancy sources, in which more than one flow pattern is found for exactly the same forcing conditions. The second is the strength and size of flows from sidewall forcing in rotating stratified fluid. Both are poorly understood but known to be important in assorted oceanic phenomena. The third project is the area of upstream flows into a critically controlled sill flow.

OBJECTIVES

For the first problem, a primary objective was to determine the quantitative role of mixing upon circulation in a circumstance where the flow can take more than one form for the same forcing conditions. For the second problem the primary objective was to document the flow patterns near a line source of heat located at mid depth on the periphery of a cylinder in a rotating stratified fluid. For the third, the question of upstream conditions and feeder currents has been a long-standing challenge.

APPROACH

First we developed prototype laboratory experiments and generated simple theories. The experiments and theories indicated the design requirements for further experiments in both problems. We then designed and conducted new laboratory experiments which are completed.

ACCOMPLISHMENTS

a. In the multiple states problems, most theories to date involve drastic simplifications with either simple box models or frictionally regulated flow. With the ultimate objective of conducting experiments for rotating flows, we have been able to develop a chamber whose floor was heated and which has an inflow of salty water near the top. This chamber was connected to a large tank of room temperature fresh water through a slot. The prototype experiments indicated that mixing within the chamber must be limited for the flows to differ from the simple box models mentioned above. Thus a theory for undermixed exchange flow was developed (theory supported by NSF) and successfully tested. The results were used to design an undermixed doubly driven chamber. b. For boundary layer processes in rotating stratified fluid, boundary layers produced by heating from the side have been produced in a laboratory cylinder of thermally stratified water on a turntable. The results are compared with calculations by Joseph Pedlosky. A variety of other theoretical solutions

have been developed which reveal these boundary layers and their strength in great detail. c. In the third problem the problem of critical control by constant potential vorticity fluid was reformulated and solved. Subsequent laboratory experiments were conducted which reveal strong influences of topographic western intensification of the upstream currents, which were not anticipated in the above theory.

SCIENTIFIC/TECHNICAL RESULTS

a. It is now clear that multiple states can be found in a variety of simple analytical numerical model problems in the general area of GFD. The undermixed doubly driven chamber exhibited a range of multiple states for large mixing, but in contrast to the well-mixed box models, the density field in the chamber varied with depth. Figure I shows a sketch of the chamber and vertical profiles of the two distinct states which were found for the same values of forcing.
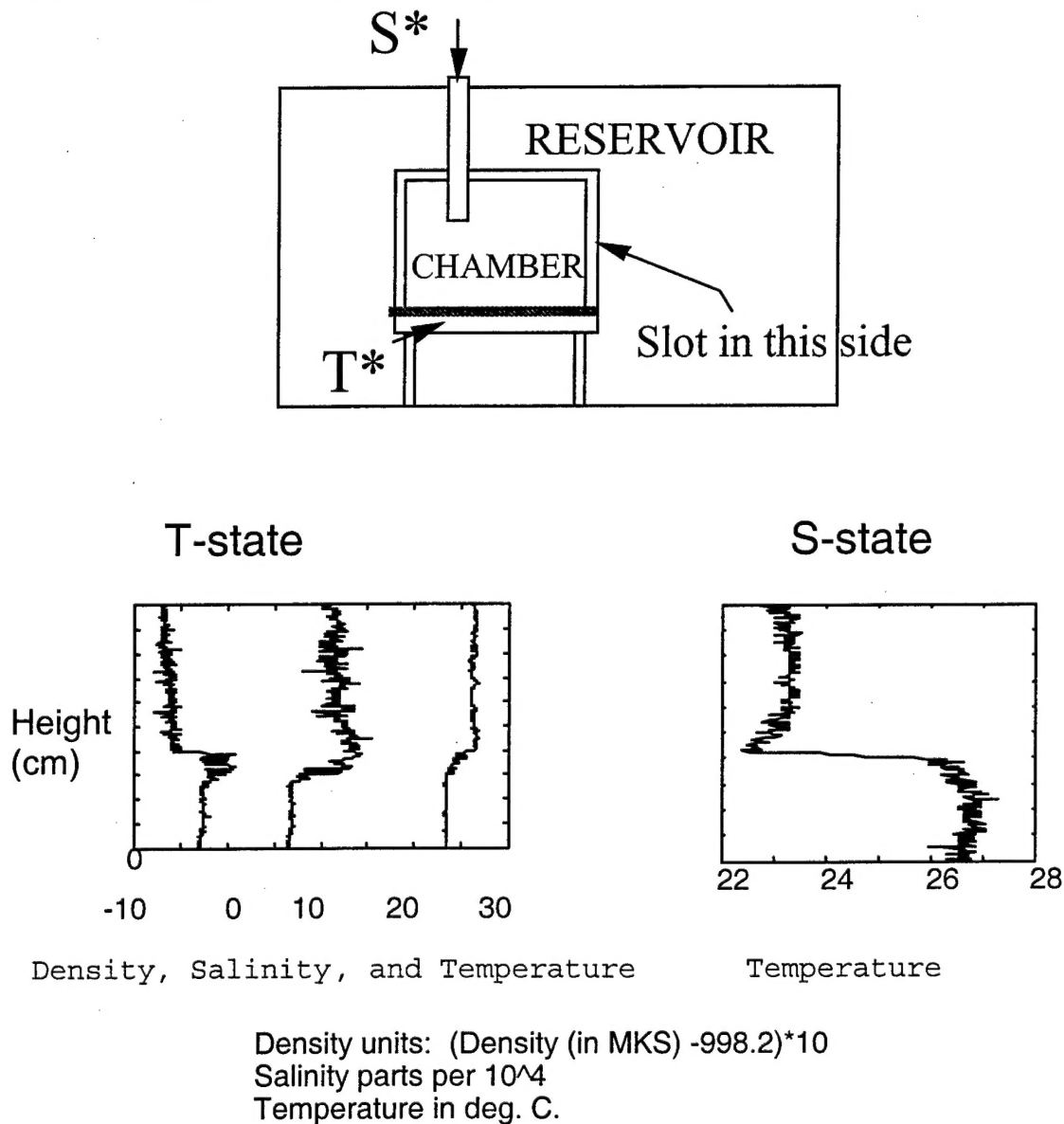

Figure 1. Sketch of the experimental chamber which produced multiple states and time dependent flows and some vertical profiles found in the chamber. Unfortunately the salinity profile was not available for the S-state.

As the tube was set to lower elevation, mixing got smaller and the flows developed pronounced time dependence so the flow in the chamber spontaneously migrated from one state to another via intermediate modes. These are presently being documented.

b. Boundary layer sizes and the magnitude of flow in laboratory experiments using stratified rotating fluids now exhibit good agreement over a broad range for a variety of boundary forcing. one prominent boundary layer is produced from either vertical or horizontal boundaries and is Rossby Radius times square root of the Prandtl number in size. Thus the strength and size of some boundary layers predicted many years ago are now confirmed by physical measurements. Such structures seem apparent in some ocean observations.

c. In the third problem the problem of critical control by constant potential vorticity fluid was formulated and solved for the case where the potential vorticity of the upstream fluid and the volume flux along the right-hand upstream wall are specified. The laboratory experiments verify relatively good conservation of potential vorticity but reveal strong influences of topographic western intensification which were not included in the above theory.

IMPACT FOR SCIENCE OR SYSTEMS APPLICATIONS
a. For large mixing, the classical box models have been verified. For limited salt mixing, a halocline develops. In some ranges the laboratory experiments possess a "climate" which is continuously fluctuating so that variables effecting density and stratification such as salinity and temperature distribution constantly change. It is clear that water bodies of many sizes, from estuaries to global oceans driven by both haline and thermal forcing could develop unsteady states such that their halocline and/or thermocline may fluctuate spontaneously.   b. Length and velocity scales for rotating stratified linearized flow have now been clearly observed. Such scales may be found in many natural settings where water is subjected to differential temperature and wind forcing. It is unlikely that numerical models would properly resolve these scales since such models use large values of diffusion to remain stable. c. The location of flows upstream of critically controlled straits or sills is very poorly understood and not documented in any ocean region to this PI's knowledge.

TRANSITIONS
The fluctuations of some well-known climate models have now been verified by physical experiment. Work to locate direct observations of catastrophic thermohaline transitions continues. We also seek observations of irregular thermohaline structures in partially mixed regions. Some of the boundary layers seen in the rotating stratified experiments may have counterparts in the ocean. Focused oceanographic studies appear to be necessary for confirmation of the boundary layer structures and the upstream flows indicated by the laboratory experiments.

RELATED PROJECTS
The findings of many model studies which reveal transitions to time-dependent flow such as Huang, Luyten and Stommel (1992), and Dewar and Huang (1995) agree with the present partially mixed experiments. Arrested Ekman suction for rotating stratified flow near a bottom (or top) was predicted first by Barcilon and Pedlosky (1967a-c) and more recently by others (MacCready and Rhines 1993, MacCready 1994, Chapman and Lentz 1994, 1997). Experiments upon eddy shedding next to a coast (Cenedese and Whitehead 1998) follow work started in previous years (Stern Chassignet and Whitehead 1996) supported by ONR. The only suggestion of the effects of topographic beta on upstream feeder currents was hypothesized for the Bering Strait inflow and produced in a laboratory study supported by ONR approximately 15 years ago (Kinder at al 1986). Upon learning of the possibility of an upstream current lying to the west of a topographic beta upstream region, T. Sanford (pri. comm.) recently sought evidence for a current upstream of the Denmark Strait overflow near the coast of Iceland and found strong currents directed toward the southwest.

REFERENCES

Barcilon and Pedlosky 1967 On the steady motions produced by a stable stratification in a rapidly rotating fluid J. Fluid Mech. 29, 273-690.

Chapman, David C. and Steven J. Lentz, 1994. Trapping of a coastal density front by the bottom boundary layer, J. Phys. Oc. 24, 1464-79.

Chapman, David C. and Steven J. Lentz, 1997. Adjustment of Stratified Flow over a Sloping Bottom, J. Physical Oc. 27, 340-356.

Cenedese, C. and J. A. Whitehead 1998 Eddy Shedding from a boundary current around a cape over a sloping bottom J. Phys. Oc. accepted.

Dewar W. K. and R. X. Huang 1995. Fluid flow in loops driven by freshwater and heat fluxes. J. Fluid Mech., 297, 153-191.

Huang, R. X., J. R. Luyten and H. M. Stommel, 1992. Multiple equilibrium states in combined thermal and saline circulation. J. Phys. Oc., 22, 231-246,1992.

Kinder, Thomas H., David C. Chapman and John A. Whitehead, Jr., 1986. Westward intensification of the mean circulation on the Bering Sea Shelf. Journal of Physical Oceanography, 16, 1217--1229.

MacCready, P. 1994 Frictional decay of abyssal boundary currents J. Marine Res., 52, 197-217.

MacCready, P., and P. B. Rhines, 1993. Slippery Bottom boundary layers on a slope. J. Phys. Oc. 23, 5-22.

Yankowsky, Alexander E. and David C. Chapman (1997) A simple theory for the fate of buoyant coastal discharges, J. Physical Oc. 27, 1386-1401.

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Publications

Borenas, K. M. and J. A. Whitehead 1998. Upstream separation in a rotating channel flow. J. Geophys Res. 103, C4 7567-7578.

Whitehead, J. A. 1998 Multiple T-S States for Estuaries, Shelves and Marginal Seas. Estuaries, 21, 278-290.

Whitehead, J. A., GK. Korotaev, and S. N. Bulgakov. 1998 Abyssal Circulation in mesoscale basins. Geophys. Astrophys. Fluid Dyn. 89 (3-4) 169-203.

Bulgakov, S. N., G. K. Korotaev, and J. A. Whitehead, 1998. A linear model of buoyancy driven circulation in the Black Sea. Deep Sea Research, accepted.

Cenedese, C. and J. A. Whitehead 1999 Eddy Shedding from a boundary current around a cape over a sloping bottom. J. Phys. Oc. accepted.

Whitehead, J. A. & Joseph Pedlosky 1999 Circulation and boundary layers in differentially heated rotating stratified fluid. Dyn. Atmos. and Oc. accepted

Whitehead, J. A., Mary Louise Timmermans, and John Salzig, 1999 Exchange flow and mixing in convective flows In Prep for J. Fluid Mech

Whitehead, J. A. and John Salzig 1999 Rotating Channel Flow: Control and upstream currents. J. Physical Oc. submitted

Published abstracts of talks

Whitehead, J. A. 1997. Multiple solutions with the same boundary conditions 50th Annual Meeting of the Division of Fluid Dynamics of the American Physical Society, San Francisco CA 23-25 November, 1997. Abstract, Bull. American Physical Soc., 42, # 11, 2153, November.

Pedlosky J. and J. A. Whitehead. 1997 Circulation and boundary layers in a differentially heated rotating stratified fluid-scales and stability. AGU Fall Meeting, paper OS41c-02. San Francisco CA. Dec. 8-12, 1997. Abstract: EOS 78 # 46 (Supplement), F373.

Whitehead J. A. 1997. Multiple equilibria in Estuaries, Shelves, Marginal Seas and Deep Convection. AGU Fall Meeting, paper OS31A-08 San Francisco CA. Dec. 8-12, 1997. Abstract: EOS 78 # 46 (Supplement), F355.

Whitehead, J. A. and J. Pedlosky, 1998 AGU Ocean Sciences Meeting, paper OS32N-11. San Diego CA. Feb. 9-13, 1998. Abstract: EOS 79 # 1 (Supplement),)S123.

Cenedese, C. and J. A. Whitehead, 1998. Eddy shedding from a boundary current around a Cape over a sloping bottom, AGU Ocean Sciences Meeting, paper OS42E-3. San Diego CA. Feb. 9-13, 1998. Abstract: EOS 79 # 1 (Supplement),)S150.

Whitehead, J. A., Mary Louise Timmermans & W. Gregory Lawson, 1998 Vertical Structure in Multiple State Undermixed flows. 51st Annual Meeting of the Division of Fluid Dynamics of the American Physical Society, Philadelphia, Pa. 22-24 November, 1998. Abstract, Bull. American Physical Soc., 43, # 9, 2083, November.

Salzig, John A. and J. A. Whitehead , 1998. Experiments and theory of constant potential vorticity hydraulic control. AGU Fall Meeting, paper U72A-19 San Francisco CA. Dec 6-10, 1998. Abstract: EOS 79 # 45 (Supplement), F7.

Whitehead, J. A., Mary Louise Elizabeth Timmermans & W. Gregg Lawson, 1998 The Production of Stratification in Multiple State Undermixed flows. AGU Fall Meeting, paper OS12D-09 San Francisco CA. Dec 6-10, 1998. Abstract: EOS 79 # 45 (Supplement), FF442.